Nuclear Inst. and Methods in Physics Research, A 936 (2019) 189–191

Contents lists available at ScienceDirect

Nuclear Inst. and Methods in Physics Research, A

journal homepage: www.elsevier.com/locate/nima

Precise measurement of 3D-position of SiPMs in the liquid xenon gamma-ray detector for the MEGII experiment

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ARTICLE INFO

Keywords:
SiPM
Liquid xenon
X-ray
Laser scanner

ABSTRACT

We developed two complementary ways to measure the position of SiPMs inside liquid xenon detector for MEG II experiment; one uses laser tools and the other uses an X-ray beam. We measured the position of all SiPMs to an accuracy of 320 μm.

Contents

1. Introduction

MEG II experiment aims to search for a lepton flavor violating $\mu^+ \to e^+\gamma$ decay to a sensitivity level of 6×10^{-14} [1].

Liquid xenon detector (XEC) measures time, energy and position of an incident gamma-ray by detecting scintillation photons from an interaction of the gamma-ray in liquid xenon. In this detector, 4092 VUV-sensitive SiPMs (Hamamatsu H.P.K, 15×15 mm^2) are installed on the incident face (Fig. 1) and 668 VUV-sensitive PMTs (Hamamatsu H.P.K, 46 mm) on the other faces. Thanks to this granular readout at the incident face, the position resolution of incident gamma-ray is expected to be ~2 mm. Therefore, the alignment of the SiPMs should be better than the resolution, but there are the following issues to address:

- SiPMs are mounted on the curved face (R∼ 65 cm).
- SiPMs are cooled at liquid xenon temperature (T = 170 K) and thermal contraction of them is not negligible.

The goal of this research is to measure the position of SiPMs to an accuracy of better than 500 μm. Two complementary measurements were performed in order to achieve this accuracy.

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https://doi.org/10.1016/j.nima.2018.10.170
Received 30 June 2018; Received in revised form 13 September 2018; Accepted 22 October 2018
Available online 26 October 2018

Fig. 1. Photosensors (SiPMs and PMTs) in XEC.

Fig. 2. Survey with Laser Scanner.

2. Laser measurement

2.1. Method

The surface of the inner wall of the liquid xenon detector was directly surveyed by Faro Edge ScanArm (Fig. 2). From the image of the surface structure, the 3D-position of the SiPMs at room temperature was reconstructed.

2.2. Reconstruction of SiPM position

All 4092 SiPMs were surveyed and the position of 426 SiPMs was nicely reconstructed to an accuracy of 120 μm. For the rest of SiPMs, the position of them was not nicely reconstructed due to the limit of the motion range of the scanner's arm and the reflection at the surface of the SiPMs.

From the position of the limited number of SiPMs, the expected relative position of all SiPMs was reconstructed as follows.

1. Fit the SiPM array with a cylindrical surface with six parameters: five for the core axis and one for the radius.
2. Project the array to the cylindrical surface.
3. Fit the $z-\phi$ position of SiPMs with a lattice assuming equal spacing. Its scale and position are fitted.
4. Calculate the position of all SiPMs as lattice points.
5. Reconstruct the 3D-position of all SiPMs with the parameters of the cylinder and the $z-\phi$ position of all SiPMs.

The reconstructed position was consistent with the measured position to an accuracy of 180 μm according to the deviation between them.

3. X-ray measurement

3.1. Method

In order to measure the position of SiPMs at LXe temperature, X-ray from ^{57}Co (122 keV) was selected as a probe because it penetrates the material in front of LXe and also interacts at the very shallow region (∼1 mm). The source of scintillation photons is so near to the inner wall that the photon distribution is concentrated to a few SiPMs. The X-ray beam is collimated to the size of 1.5×40 mm^2 by a brass collimator, which is mounted on a rotational stage on a linear stage. The beam is aligned to an accuracy of 30 μm in z and 80 μm in ϕ. The incident face was scanned with the beam from outside the detector, and the trigger rate of a SiPM is shown in Fig. 3 as a function of the beam position. The peak structure is used to determine the SiPM position. The main background is external irradiation that gives a large energy deposit such as cosmic-ray.

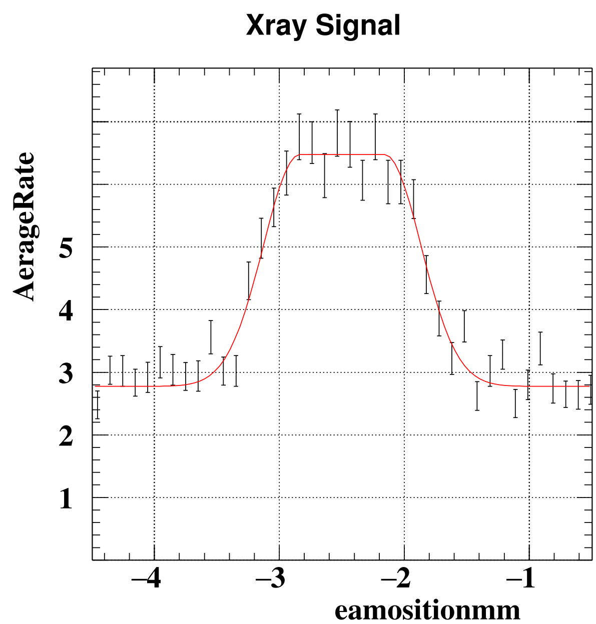

Fig. 3. X-ray Signal and fitting function.

3.2. Result

The signal of each SiPM is fitted with a symmetric function with a flat line and two gaussians whose peak is smoothly connected to the line. Then, the position is reconstructed as its mean. The position of 1214 SiPMs was measured with an accuracy of 250 μm according to the spacing in z direction.

The position of the rest of SiPMs could not be measured because the magnet in front of the detector absorbed the X-ray.

4. Combination

4.1. Transformation and fitting

If the whole SiPM array shrinks uniformly, the measured position at room temperature is translated to that at LXe temperature as shown in Eq. (1). In Eq. (1), a corresponds to the scale of the thermal contraction and $R(\alpha,\beta,\gamma)$ means an rotation. $\vec{c}_{offset}$ is a global offset. The transformed 3D-position is fitted to the 2D-position from X-ray measurement.

$$\vec{x}_{laser} \mapsto (1-a)R(\alpha,\beta,\gamma)\vec{x}_{laser} + \vec{c}_{offset} \tag{1}$$

After fitting, the position of both measurements was consistent with each other to an accuracy of 300 μm. As a result, the position of all SiPMs at LXe temperature is reconstructed.

4.2. Scale of thermal contraction

The expected value a_{exp} can be calculated based on the thermal expansion coefficient of the detector material C_m, and the measured value, a_{data}, can be compared as follows.

$$a_{exp} = C_m \Delta T = 16 \pm 1 \text{ ppm K}^{-1} \cdot 110 \pm 10 \text{ deg} \tag{2}$$

$$= 1.8 \pm 0.2 \times 10^{-3} \tag{3}$$

$$a_{data} = 1.76 \pm 0.14 \times 10^{-3} \tag{4}$$

The measured value was consistent with the expectation.

5. Conclusion

Two complementary measurements were performed for the alignment of the SiPMs in the liquid xenon detector. Laser measurements gave the 3D-position of SiPMs at room temperature to an accuracy of 180 μm, whereas X-ray measurement gave the 2D-position at LXe temperature to an accuracy of 250 μm.

By combination of both measurements, the 3D-position of all SiPMs at LXe temperature is reconstructed to an accuracy of 320 μm.

Acknowledgments

We thank PSI as a host laboratory and UCI and UTokyo for financial support. This work was supported by JSPS KAKENHI, Japan, Grant Number 26000004.

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